*Interdisciplinary Studies on Applied Science, 3(1):1–19, 2026. DOI: 10.58613/isas311*

**Interdisciplinary Studies on Applied Science**

*Journal homepage: https://www.gpub.org/journal-details.php?journal-id=42*

ISSN (E): 3048-877X

***Research Article***

# The role of beetles and flies as silent witnesses in forensic evidence

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**Article Info**

***Keywords:*** *Forensic Entomology, Blue Metal Fly, Forensic Beetles, Forensics, Insect Analysis, Crime Scene, Time of Death Estimation.*

***Received:*** *09.12.2025;*
***Accepted:*** *03.01.2026;*
***Published:*** *11.01.2026*



**Abstract**

Forensic entomology is one of the most effective and accurate methods used by law enforcement officers at crime scenes to identify suspects and decide the reason of death. This research reviews, studies, and examines various insect species found on decomposing bodies at different post-mortem intervals. It also aims to analyze and evaluate the effectiveness of forensic entomology compared to other forensic methods used as evidence. This brief paper summarizes the most important ways in which entomology currently contributes to criminal investigations, including complex criminal cases, suicides, and homicides. This research provides a comprehensive scientific review of this field, covering its biological foundations, field and laboratory procedures, important forensic insect species, applied studies, and the challenges it faces.

## 1. Introduction

Forensic entomology is a complex discipline that has emerged in recent years in the field of forensic science. This specialty focuses on analyzing the information provided by insects about the crime scene or time of death, by studying insects that feed on human tissue after death, in addition to analyzing the biological environment surrounding the body. This field is a vivid example of the integration of life sciences and criminal investigations, as insects can provide evidence that cannot be detected through traditional medical examinations [1]. The development of the use of insects in criminal surveys until it became one of the branches of modern entomology, which is known as forensic entomology. Several societies emerged in the 1990s and early 2000s, which include many entomologists interested in forensic entomology, and the most prominent of these societies are: The American Society and the European Society for Forensic Entomology [2]. Ancient studies indicate that the Egyptians were studying the problem of insects in the mummification process after death [3]. More recently, forensic entomology has become part of the judicial system and criminal investigations in many countries around the world [4]. Criminal courts worldwide rely on information obtained from insects to decide the period of death. Strategies and procedures have been developed for collecting and analyzing insect evidence found at crime scenes [5].

### The aim of the study

The purpose of this research is to determine the importance of forensic entomology in approximating period of death. Evaluate the accuracy of relying on insect life cycles in crime scene analysis. Provide practical recommendations for adopting this science in criminal investigations. Contribute to the discovery and development of an important means of proof.

### Importance of the study

The insect is a witness that does not know perjury, or collusion with criminals against the victim, and does not resort to cheap lies for personal gain, nor does it accept the corruption of people, and mutual interest deals, only sides with absolute justice alone, so it reveals crimes and pursues killers, and grants innocence to the unjustly and slanderously accused, and investigators can use it in most criminal investigations. Data obtained from insects is useful in criminal investigations, highlighting the importance of entomology in the field of forensic evidence. The more the means and methods of committing the crime develop and diversify, the means of detecting it must develop, and with the complexity of the search for the truth, the means and tools of tracking and pursuing the perpetrators have also changed.

## 2. Forensic Entomology

### 2.1. Historical Overview of Forensic Entomology

The use of insects in criminal investigations dates back more than seven centuries. The Chinese scholar Song Tzu (宋慈) was among the first to point out the potential role of insects in solving crimes in his famous work, ”The Washing Away of Wrongs”, inscribed in 1247. In one case, Song Tzu describes how flies congregating on an apparently washed but bloody cleaver blade helped identify the killer. This documentation is among the first evidence of the use of insect behavior in criminal investigations [6]. In 1855, French forensic pathologist Dr. Berger d’Arbois used entomology to solve complex criminal cases, notably the case of an infant’s body found in a house in Versailles, France. Dr. Berger d’Arbois meticulously analyzed the insects, such as flies and beetles, found on the body. He determined that the decomposition process had occurred several years prior, indicating that the death had taken place before the current family moved into the house. His analysis helped rule out the current suspects and directed the investigation toward the previous occupants. This case is considered the first practical step in the use of forensic entomology as a lawful tool of evidence in investigations, representing a successful integration of biological observation and judicial application, thus paving the way for the development of this vital branch of criminal science [7]. Forensic entomology began to take on a scientific character during the nineteenth century, with the emergence of field studies on insect colonization of corpses, particularly in France, where the researcher Jean-Pierre Mégnin, a veterinarian and entomologist, published pioneering work on the sequence of insect species appearing on corpses. At the same time, England saw initial uses of this science in criminal cases, but without it gaining a clear institutional character [8]. Insects were not officially linked to death until 1968. That year, Ken Smith prepared a manual called The Manual of Forensic Entomology. In it, Smith listed the different types of insects that are attracted to corpses, and also identified the insects that appear at each stage of decomposition [9].

### 2.2. Previous studies

Forensic entomology has advanced significantly in current years and is now considered a main science in the discovery of forensic evidence. Criminal courts and forensic investigators in many developed countries have begun using insects as precise evidence to aid in crime scene investigation, determining time of death, and transporting bodies, thus contributing to the advancement of this science. Despite this global progress, the application of forensic entomology in the Middle East remains limited. Interest in it is confined to individual initiatives by some Arab researchers and forensic doctors, without official recognition as a field within judicial systems or forensic medicine centers. Specialized forensic laboratories are still absent in any of the countries of the region, and forensic entomology is not regularly taught in medical or forensic science faculties. In this context, Iraq has emerged as an example of growing scientific interest, where local surveys and epidemiological studies are being conducted to identify and classify insects of forensic interest. Among the most prominent of these scientific efforts are the pioneering studies conducted by the late Professor Dr. Muhammad Salih Abdul Rasoul, who made a significant contribution to establishing the scientific foundations of this field in the Iraqi environment. He was able to identify 19 species of flies associated with the decomposition of corpses, belonging to four different families [10]. He also identified (4) species of beetles belonging to the Coleoptera family, which play an significant role in the advanced stages of corpse decomposition. Abdul–Rassoul et al. [11] Researcher Haider Naeem Mohammed Ali (2020) conducted a large-scale field survey in Karbala Governorate. This study focused on identifying and classifying insect species that play a significant role in postmortem decomposition and determining the time of death. The study identified 26 insect species belonging to 11 families within the order Diptera. Additionally, 10 new species were identified and recorded for the first time in the list of insects found in the Iraqi environment. In addition, the study included the recording of (11) beetle species belonging to (4) different families within the Coleoptera order, including (5) new species for the Iraqi record. Regarding the Hymenoptera order, seven species were recorded, including various species of ants (Formicidae) that participate in the advanced stages of decomposition. Al-Ashbal et al. [12] Forensic science did not emerge clearly until the beginning of the twentieth century when Mr. Edmond Locard established the first laboratory in history for crime scene investigations, in the French city of Lyon in 1910. Locard was so influenced by the character of the detective Sherlock Holmes that he was called the ”French Sherlock Holmes”. His greatest contribution was the Locard principle, which states that (every contact leaves a trace). The principles of crime scene analysis were not formally defined until 1931, when Mrs. Frances Glessner Lee founded the Harvard School of Forensic Medicine. She prepared a laboratory for unsolved death and murder sites, and it became a teaching tool for medical students [13].

### 2.3. Types of insects found in decomposing bodies

Forensic entomology is well-defined as the branch of entomology that studies arthropods related with crime scenes, particularly corpses, with the aim of extracting accurate and useful information for criminal investigations, such as estimating the time or circumstances of death. Arthropods, particularly blue metal flies (Calliphora spp.), have received widespread attention in forensic, medical, and legal fields due to their high accuracy as bioindicators in analyzing the stages of decomposition and environmental changes. Continuous research efforts by scientists and researchers have contributed to the development of this field, resulting in a series of studies that have established the foundations for the use of flies in forensic settings, to the point that they have become scientifically and judicially recognized investigative tools. According to Smith (1986), insects found on rotting corpses are classified into four chief groups, based on their ecological role and relationship to the corpse [9, 14].

### Necrophagous

Necrophagous insects are among the most important groups of insects used in crime scene analysis and postmortem interval (PMI) estimation. They feed directly on the soft tissues of corpses and are among the main animals to colonize a body next death. The most prominent of these species are Figure 1 [15].

- **Blue metal flies (Calliphoridae):** These are among the major insects to reach at a corpse, laying their eggs in body openings or wounds. These eggs later hatch into larvae that feed on the decaying tissue. This species is considered an important indicator of early decomposition.
- **Flesh flies (Sarcophagidae):** These belong to the Diptera and are characterized by laying their larvae directly on the corpse (viviparous). They are also among the first colonizers of the corpse.
- **Skin beetles (Dermestidae):** These appear in the late stages of decomposition, feeding on dry tissue and skin, and also contribute to the cleaning of the skeleton.
- **Corpse beetles (Silphidae):** Known for their role in decomposing corpses in the middle and late stages of decomposition, they are attracted to the odors of decay and play a dual role in feeding and colonizing.

These species are among the insects most closely associated with corpses in terms of feeding and reproduction, and they provide vital clues about the time, location, and circumstances of death, making them a central tool in modern forensic analysis [9].

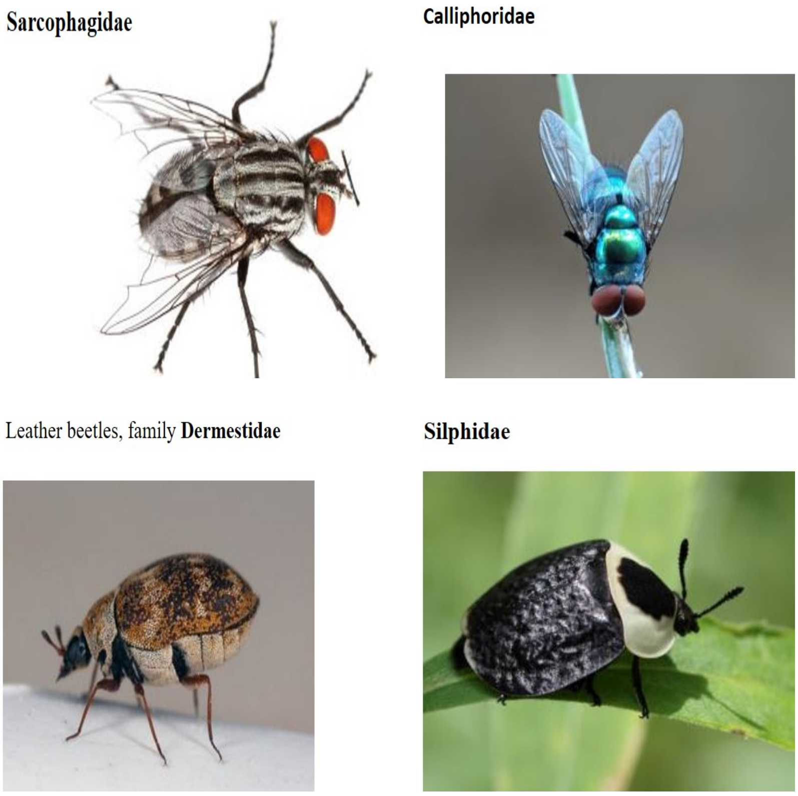


**Figure 1:** Necrophagous species [16]

### Predators and Parasites of Necrophagous

These types of insects Figure 2 either prey on or parasitize (larvae and pupae) of carrion-eating insects. They include beetles from the families Staphylinidae, Silphidae and Histeridae, as well as true flies from the families Muscidae, Calliphoridae and Stratiomyidae, as well as wasps from the order Hymenoptera [15].

**Histeridae beetles** **Staphylinidae beetles**

**Figure 2:** Predators on Necrophagous [17]

**Omnivorous species**

Insect omnivores are part of the biodegradation system of corpses. They include a group of insects that feedstuff on both the tissues of the corpse and other insects that colonize it, whether as carrion feeders or parasites. The most prominent of these species are: ants (Formicidae), wasps (Vespidae, and other Hymenoptera), and some beetles (such as some members of the Staphylinidae family). These insects are characterized by their diverse feeding behavior, as they feed on the soft muscles of the corpse and prey on or attack the larvae and pupae of other insects, especially cadaver flies such as Calliphoridae and Sarcophagidae [18]. The presence of these insects on the corpse is a complicating factor in the decomposition process, as they:

- Slow the development of pioneer insects (such as blue metal flies) by preying on or displacing them.
- Delay the natural decomposition process by interfering with insect succession.
- They may affect the accuracy of time-of-death estimation if not taken into account in forensic entomological analysis. Therefore, omnivorous insects are considered influential elements in the decomposition environment of a corpse, and their presence and behavior must be carefully analyzed to avoid errors in forensic chronological interpretation [19].

**Adventive species**

Adventive species are arthropods that are not directly part of the decomposition chain, but exploit the presence of corpses as a temporary source of food, shelter, or to expand their natural habitat. The most prominent of these species are jumping tails (*Collembola*), spiders (*Araneae*), and millipedes (*Diplopoda*). These organisms are found in the surrounding environment and are attracted to corpses for reasons unrelated to the direct decomposition process, such as shelter or consumption of other insects. Although they do not participate in the breakdown of corpse tissue, their presence on corpses can confuse the interpretation of evidence if they are not distinguished from forensic insects. Flies, beetles, weevils, and mites are among the main organisms involved in the biodegradation process. They play complementary roles in decomposing a corpse, with their ecological relationships overlapping as follows [1] .

- Parasitic and predatory flies, such as some species of Muscidae and Stratiomyidae, prey on the larvae of other species.
- Predatory beetles such as Staphylinidae and Histeridae attack fly larvae.
- Parasitic wasps of the order Hymenoptera parasitize fly larvae, preventing their full development.

## 2.4. Types of insects used in forensic investigation

**Flies**

Flies and beetles are among the greatest important insect groups used in forensic surveys. The sequence of insect colonization of a body depends on the periods of decomposition and the condition of the body [20]. The Diptera (flies) order is the first group to arrive at a body, often beginning colonization immediately after death. Among the most prominent families in this order is the Calliphoridae family, popularly known as "metal flies" due to their bright colors, such as metallic blue or green. The blue bottle fly Figure 1 is one of the most important species in forensics, as it is typically the principal to colonize a body and appears in large numbers, making it an accurate tool for estimating the smallest time since death (PMI) [21]. The blowfly goes through four stages in its life cycle : first, the egg, second, the larva (which includes three stages: first, second, and third), third, the pupa (pupa), and finally, the adult fly, which is the fourth stage. The larva is the active feeding phase. After feeding, the larvae travel away from the body to burrow into the soil (in outdoor cases) or hide under furniture and carpets (indoors). They then begin their transformation into the pupae inside the "pupa," a hard, dark casing that represents the final stage before the adult fly emerges [22].

The blowfly belongs to the family Calliphoridae, which includes more than 1,100 known species. Adult flies do not bite humans or animals, but feed on the fluids produced by decomposing carcasses, garbage, and dung. Despite their behavior, which is considered annoying to humans, these flies play a vital ecological role by accelerating the decomposition of organic matter [23]. Blowfly growth rates are used to estimate time of death, particularly during the first weeks after death. However, accurate estimates require detailed knowledge of the growth of different species under environmental conditions similar to those of a crime scene [24]. Adult female blowflies reach at a corpse within some minutes and lay approximately 250 eggs in usual body openings or exposed wounds. The eggs hatch within 24 hours into larvae. The third-stage larvae create heat that can increase the local temperature by more than (10°C). After completing feeding, the larvae migrate away and transform into adult flies. The duration of fly development is used as a key pointer for estimating the period of death, as shown in [25].

The Sarcophagidae family is another greatest important family of forensic flies after the Calliphoridae Figure 3. Members of this family are categorized by their big size and are simply identifiable to the naked eye thanks to their unique color pattern, which consists of dark and gray bands on the thorax and a square-shaped abdomen. Flesh flies often have bright red eyes, making them easy to identify at a crime scene. A notable physiological characteristic of flesh flies is that they do not lay eggs, as most other fly species do. Instead, they follow an ovoviviparity strategy, in which the eggs hatch inside the female and the larvae are born directly. As a result, females deposit live larvae on the carcass, giving them a competitive advantage, as the larvae begin feeding immediately, without having to wait for the incubation period of the eggs, as in blow flies. Flesh flies typically arrive at the carcass slightly later than blow flies, but they compensate for this by the speed of their larval development. Competition often occurs between the two species for larval laying sites, and flesh flies have been observed in some cases using their legs to kick rival flies in an attempt to gain control of the most suitable sites [26].

**Figure 3:** Common flesh fly (Sarcophaga carnaria) on a mole carcass [27]

**Family III:** Muscidae, within the order Diptera, includes species that closely resemble blowflies in general appearance, but rarely display the metallic luster characteristic of Calliphoridae. Adult houseflies have spongy mouthparts designed for sucking fluids. These flies typically feed on bodily fluids such as sweat or solid food that can be dissolved by saliva. Although the larvae often feed on dung and manure, they can also be found on corpses, especially in the appropriate developmental environment. The best-known species in this family is Musca domestica (the true housefly), which has spread worldwide as a result of human interaction. Although the adults are typically seen feeding on fluids leaking from a corpse, the larvae often prefer dung as a food source. Adult Muscidae are most commonly originate on corpses in the initial steps of decomposition, when the body is still moist and fluid-rich. Another species in this family is Australophyra rostrata, which is attracted to corpses in the late periods of decomposition, after most of the larvae have disappeared, but before the body is completely dry [28].

**Family IV:** Piophilidae, commonly known as cheese flies, is a common family within the order Diptera and is of particular forensic interest during the late stages of decomposition. Their most striking biological characteristic is their jumping larvae, which exhibit a unique defensive behavior: the ability to leap using sudden body movements. This behavior is characteristic of the common species Piophila casei, Figure 4 usually identified as the jumping cheese fly, which is found worldwide. Cheese flies are typically observed in the late steps of decomposition, especially when the body begins to ferment and produce strong, unpleasant odors. Females are attracted to these scents and lay their larvae on the corpse, often observed in states of advanced wet decomposition. Interestingly, some biological studies have documented large numbers of Piophilidae flies, with 4,363 flies recovered from cocoons derived from a single sheep head. Larvae of these flies have also been found in coffins buried at depths of up to 3 meters and in corpses up to 10 years old, demonstrating their high adaptability and continued survival under harsh burial conditions [29].

**Figure 4:** Cheese Fly (Piophila casei) [30]

**Family V:** Chironomidae, belongs to the order Diptera and is one of the most common insects found in aquatic environments, particularly around submerged bodies. The insect has four stages in its life cycle: egg, larva, pupa (which is aquatic), and finally adult. Despite their frequent presence on corpses, their use in forensic science remains limited. In one study, the body of a woman was found in a river in Granada. It appeared the body had been in the river for an extended period. After the completion of forensic and clinical examinations, the reason of death was determined to be drowning. However, during the examination of the body, scalp samples were collected, revealing larvae resembling Chironomidae flies. Through external morphological analysis, these larvae were identified as fourth-instar larvae of Chironomus riparius, a known aquatic species belonging to the Chironomidae family. To further the diagnosis, cytochrome oxidase I (COI) gene sequencing was performed, confirming the taxonomic identity of the specimen. Biological data related to the C. riparius fly, particularly at low temperatures, were crucial for estimating the post-immersion period (PSI). Based on growth and metamorphosis rates, the body was estimated to have been submerged for 16–17 days, helping investigators narrow down the timeframe of the incident [31].

**Family VI:** Dark Soldier Fly (Stratiomyidae): The dark soldier fly (*Hermetia illucens*), a member of the Stratiomyidae family. Dark soldier flies are found in the advanced periods of decomposition and are used to estimate post-mortem time. Unlike other flies, their larvae prefer organic environments rich in decay and are often found on decomposing bodies. In a forensic field study in Brazil, the dark soldier fly life cycle was used to estimation post-mortem time in an investigation into the kidnapping and murder of a child. The body was found 42 days after the reported abduction and was in an advanced phase of decomposition. *Hermetia illucens* larvae were originate attached to the tissues of the corpse. Through field observation, these larvae emerged as adults within 25–26 days, allowing experts to estimate the egg-laying time on the body as 24–25 days after the disappearance. Based on the ecological characteristics and delayed reproductive behavior of this species, it was concluded that the body became available for egg-laying shortly after death, which is constant with the theory that the child was killed directly after abduction. This case clearly exemplifies the use of specialized biological characteristics of unconventional fly species to enhance the accuracy of time-of-death estimations, especially when the body is past the early stages of decomposition in which other species such as Calliphoridae and Sarcophagidae are more common [32].

**Beetles**

Along with insects of the order Diptera, Coleoptera (beetles) are another major group associated with corpses in forensic entomology. Some beetle families are attracted to the various stages of decomposition. Unlike flies, beetles have nibbling mouthparts, enabling them to feed on more solid materials than fly larvae, which prefer semi-liquid materials. Beetles are attracted to corpses by chemical cues released during decomposition. Predatory beetles, such as ladybirds (Staphylinidae), arrive in the primary phases of decomposition and prey on fly larvae. They are among the first beetles to appear on corpses. Skin beetles (Dermestidae) and burrowing beetles (Trogidae), reach in the later steps of decomposition and are characterized by their ability to feed on dry or hardened tissue. This arrival sequence shows that beetles can play an main role in determining the stage of decomposition, enhancing the accuracy of post-mortem interval (PMI) estimation, especially in cases where the body has progressed to later stages [33].

Beetles (order Coleoptera) are vital components of insect communities that succeed in carcasses and represent an effective tool for estimating the post-mortem interval (PMI), especially in advanced stages of decomposition. Among the families of interest in forensic contexts, the following are the most prominent: carrion beetles (Silphidae), dung beetles (Staphylinidae), scavenger beetles (Histeridae), late carrion beetles (Trogidae), skin beetles (Dermestidae), pork beetles (Cleridae), nitidulidae, and ground beetles (Carabidae). Additional families have been reported in various field experiments, reflecting the diversity of cadaver beetles and their diverse ecological roles. Cadaver beetles can be classified according to their timing of arrival and feeding mechanisms into three main functional groups [34].

- **Predatory adult beetles:** These beetles arrive in the primary stages of decomposition and are usually predatory adults. Beetle eggs reach the carcass, and the developing larvae prey on other larvae. Examples include dung beetles (Staphylinidae) and carrion beetles (Histeridae).
- **Late-onset organisms:** These insects avoid moisture and arrive during the dry stages of decomposition, feeding on skin and tendons. Examples include skin beetles (Dermestidae) and pig beetles (Cleridae).
- **Diverse Diets:** Such as the Silphidae, which are characterized by a diverse diet; they feed on carrion remains. Trogidae beetles also show a minor role in the decomposition of dry remains.

Forensic entomologists have realized that beetles tell an important part of the story of death, especially in the later phases of decomposition, when the body becomes drier and fly populations decline. Analyzing the succession and temporal diversity of beetles has enabled researchers to more accurately estimate the time of death. The change in beetle diversity over time demonstrates clear evidence of ecological succession, which is essential for interpreting the circumstances surrounding death and the site of decomposition [35].

## 2.5. Steps of Corpse Decomposition and the Role of Insects

Once death occurs, autolysis begins within the body, with cellular enzymes digesting cells from the inside out. This is followed by bacterial decomposition, particularly by bacteria residing in the digestive tract, which decomposes soft tissue and produces a mixture of liquids and gases such as hydrogen sulfide $H_2S$, carbon dioxide $CO_2$, methane $CH_4$, ammonia $NH_3$, sulfur dioxide $SO_2$, and hydrogen $H_2$. These volatile compounds, known as cadaveric volatile organic compounds (CVOCs), help attract insects to corpses. Researchers were able to isolate and identify these compounds during the several stages of decomposition, confirming that the type and concentration of volatile molecules help guide insect behavior and attract different species [36]. K. Tullies and M.L. Goff divides the decomposition of a body into five main stages Table 1 related to the succession of insect colonies, as follows Figure 5 [37].

**Table 1:** Stages of Decomposition and Associated Insect Activity [36]

| Stage | Associated Insect Activity | Physical Characteristics |
|---|---|---|
| 1. Fresh Stage | Blowflies (Calliphoridae) arrive and begin laying eggs on natural openings. | Begins immediately after death; no visible external signs of decomposition. |
| 2. Bloat Stage | Increased fly activity; eggs hatch into larvae (maggots). | Accumulation of gases causes abdominal swelling; strong odors are emitted. |
| 3. Active Decay Stage | Peak maggot activity; predatory beetles (e.g., Staphylinidae) arrive. | Massive breakdown of soft tissues; body fluids seep out; strong odor persists. |
| 4. Advanced Decay Stage | Decline in fly activity; dermestid beetles and late-arriving insects appear. | Decrease in body fluids; remaining tissue is more desiccated and leathery. |
| 5. Dry/Skeletal Stage | Dominance of beetles (e.g., Dermestidae, Cleridae); flies are mostly absent. | Only bones, dried skin, and cartilage remain. |


**Figure 5:** Stages of decomposition [37]

**Fresh stage (days 1-2)**

This phase initiates at the instant of death and remains until signs of bloating look. During this stage, autolysis occurs as a result of enzymatic activity within the cells, without any obvious morphological changes to the naked eye. Although no visible changes or distinctive odors are observed at this stage, chemicals produced by cell disintegration begin to attract insects within the principal 10 minutes after death. However, egg laying is not observed in this stage. Studies indicate that estimating the time of death based on entomological data next 24 hours is additional accurate than traditional forensic estimates based on soft tissue checkup. Although signs of decomposition are not evident, cellular dissolution actually begins at this stage, marking the actual beginning of the forensic decomposition process Figure 6 [38].

**Figure 6:** Pig carcass in the first stage of decomposition [39]

**Bloated stage (days 2-7)**

This stage begins with the accumulation of gases resulting from bacterial activity in the digestive system, causing the body to swell and expand, making morphological changes easily observable. This stage marks the beginning of visible changes, with skin discoloration and the appearance of foul odors resulting from gases such as indole and skatole. Insects, particularly blue-green flies of the Calliphoridae genus, begin laying eggs around the natural openings of the corpse ( mouth, eyes ,nose, ears,). This coincides with increased activity of larvae, which hatch within a short period, significantly enhancing the decomposition process Figure 7 [40].

**Figure 7:** Pig carcass in bloated appearance from decomposition [39]

**Decay stage (days 5-13)**

This phase initiates with rupture of the abdominal wall due to the accumulation of internal gases, leading to the shrinkage of the corpse and marking the end of the bloating stage. The internal temperature of the corpse rises to approximately 14°C above the ambient temperature due to the intense activity of larvae and bacteria, then gradually decreases toward the end of the stage, indicating a decline in internal biological activity. This period is one of the most odorous stages of decomposition, peaking as the temperature rises and then decreasing as it decreases. By the tenth day, the weight of the corpse decreases significantly due to the loss of tissue and fluids, as the biomass of the corpse is converted into larval biomass, particularly for those of the order Diptera. At the end of this stage, the larvae begin to leave the corpse in search of a suitable environment to develop into pupae, marking the beginning of advanced decomposition Figure 8 [36].

**Figure 8:** Pig carcass in advanced stage of decomposition [39]

**Post-decay step (days 10-23)**

This phase begins when most Diptera larvae leave the body, completing their life cycle and transitioning to the pupal stage outside the body. During this stage, the carcass remains mostly composed of bone fragments, cartilage, hair, and small fragments of tissue that were not completely consumed. A great amount of wet, sticky material identified as body decomposition by-products (BOD) is also observed. These are a mixture of decomposing body fluids, tissue fragments, and waste products resulting from microbial and larval activity. Insects decline at this stage, especially Diptera, while other species, such as some beetles (Dermestidae), begin to dominate the ecological landscape. This stage also marks the transition to the skeletal stage, where biological activity gradually decreases, and the environment begins to stabilize chemically and biologically Figure 9 [41].

**Figure 9:** Pig carcass in active decomposition stage [39]

**Remains step (days 18-90+)**

This phase is known as the final stage in the decomposition chain and is characterized by the survival of the skeleton with only a few remnants of cartilage and dry tissue. Remains of by-products of decomposition (BOD) are also observed, almost completely dried, reducing the environmental attractiveness of insects. The change from the post-decomposition stage to this stage occurs gradually, with the numbers of larvae and adults of the diptera decidua declining significantly, and the intense insect activity that characterized the previous stages is absent. Some specialized beetles, such as the Dermestidae and Trogidae, often remain active during this stage, feeding on dry tissue or keratinous remains. This stage presents a challenge in determining the precise period of death due to the absence of active biological changes, requiring reliance on subtle environmental factors or delayed insect indicators, if present Figure 11 [42].

**Figure 10:** Blowflies and their larvae on the carcass of a South African hystrix

## 2.6. Postmortem Interval - PMI

Forensic entomology plays an vital role in determining the time elapsed since death (PMI) by documenting the insect species associated with the body, their life cycles and developmental stages, and their behavior on decomposing corpses. Analyzing insect communities and their chronological sequence on a body can provide an exact estimate of the time then death. In addition to estimating PMI, entomological evidence may reveal additional information of forensic importance, such as whether the body was moved from one location to another after death or whether it was subject to tampering—either by predators or the killer who may have returned to the crime scene later. However, the major and best public use of forensic entomology now is to decide the time of death, particularly in cases beyond 72 hours postmortem, when other forensic methods (such as body temperature analysis or rigor mortis) are less accurate or inapplicable. In such late-stage cases, entomological evidence is often the most reliable, and sometimes the only, source available for estimating the time of death, especially in

**Figure 11:** Pig carcass in dry decomposition stage/remains

complex environmental conditions or when advanced decomposition is present. The use of entomologists in estimating PMI relies on two main approaches [9].

**Larval Development Analysis**

This methodis greatest widely used and accurate procedures in forensic entomology for estimating the post-mortem interval (PMI), especially during the first days after death. It relies on studying the ages of developing insects on the body, particularly fly larvae from the Calliphoridae family (blue and green flies), which are among the principal species to reach at the body and lay their eggs in moist or damaged areas. This method involves collecting larvae from various locations on the body or the surrounding environment, and then determining their developmental stage (egg, first, second, or third instar larva, pupa, or adult) using microscopic examination or length and mass measurements. Accumulated degree hours (ADH) or accumulated degree days (ADD) are used to calculate the time since egg-laying, which represents the minimum period of time since death, given that flies do not lay eggs until shortly after death [43].

**Advantages of the method:** Highly accurate within the first few days after death (usually up to 7-10 days). Based on measurable biological data and laboratory verification. Very useful when the body is relatively fresh. Its limitations require precise knowledge of the local insect species and are affected by environmental factors (temperature, humidity, location of the body). Less effective in advanced stages of decomposition, where the larvae have pupated or have left the body [43].

**Insect Succession Analysis**

This method is an effective tool in forensic entomology, especially when dealing with bodies that have passed the primary phases of decomposition and reached advanced stages such as post-decomposition or the remains stage. This method is based on the principle that different insect species colonize a body according to a precise ecological chronology, with each species appearing at a specific stage of biological decomposition. For example, fly species from the Calliphoridae family (such as blue and green flies) are the main to reach at a body during the fresh and bloated phase, while beetles from the Dermestidae or Silphidae families begin arriving at later stages, feeding on dry tissue or keratin residues. This natural sequence is known as insect succession and is documented in the field and laboratory in various environments to create reference databases. This method can compare insect species found on a body with recorded biological succession patterns in the same area, permitting for estimate of the approximate time since death (PMI), even in cases of severe decomposition where no active larvae are present [44].

**Advantages of the method:** Effective in estimating PMI in late stages of decomposition (after 10 days and above). It can be used in complex environments such as partially buried or exposed bodies for long periods. It helps reveal whether the body has been moved or manipulated based on the mismatch between the insects and the environment. Its limitations require a comprehensive knowledge of the local insects and their succession patterns. It is also very sensitive to environmental changes that may affect insect succession and is less accurate than analyzing developmental stages in the early stages of death [44].

There are many organisms that decompose the human body after death, and may reach several thousand in one corpse, the most prominent of which are larvae, bacteria, and various insects. Not all of these organisms begin to decompose the human body or corpse at the same time, as each phase of decomposition is categorized by the presence of a known type of organism. Some organisms pave the way for the next type of other organisms to decompose the corpse. For example, a certain type of bacteria may secrete some odors that attract some fungi to start the next stage of decomposition. Each ecosystem is characterized by containing microorganisms that are not found in another environment, which contributes to the process of accelerating or slowing down the decomposition processes. The analysis of the corpse by organisms in several stages helps experts and specialists to know a lot of valuable information about the corpse, such as: the time of death and its place of occurrence [45].

### 2.7. Classification of Forensic Entomology

Lord and Stevenson scientifically classified forensic entomology dividing it into three main branches that form the foundation of the field. This classification has been adopted as a reference in many forensic applications. It includes the following Table 2 [46, 47].

**Table 2:** Classification of Forensic Entomology [48]

| Branch | Common Insect Species | Application Field | Main Objectives |
|---|---|---|---|
| 1. Urban Entomology | Ants, cockroaches, termites, bed bugs | Urban environments, residential and industrial buildings | 1. Investigate building damage<br>2. Assess public health concerns<br>3. Support civil legal claims |
| 2. Stored-Product Entomology | Grain beetles, moths, small flies | Food industry, storage facilities, commercial markets | 1. Detect food fraud<br>2. Identify sources of contamination<br>3. Evaluate damage to stored food products |
| 3. Medicolegal Forensic Entomology | Blowflies (Calliphoridae), beetles, small dipterans | Crime scenes (homicide, suicide, sexual assault, body concealment) | 1. Estimate postmortem interval (PMI)<br>2. Determine time and place of death<br>3. Detect body movement or tampering |

### 2.8. Methods of collecting insect evidence

It is essential to meticulously document and preserve all details of the insect collection process. A systematic approach must be followed to ensure accurate and reliable species identification Table 3 [49].

**Table 3:** Forensic Entomology Evidence Collection Summary [1, 49]

| Procedure / Tool | Purpose | Notes & Recommendations |
|---|---|---|
| Do not wash the body before sampling | To avoid destroying insect evidence | Always collect from the scene before moving to the morgue |
| Collect larvae from different body regions and surroundings | To obtain full representation of insect colonization stages | Larvae often concentrate in head, ears, wounds; mature larvae burrow into soil |
| Collect multiple insect stages | For accurate developmental analysis | Include various sizes and stages; aim for ∼20 large larvae and some pupae |
| Use hand nets and aspirators | Efficient collection of live insects | Preserve alive or kill depending on study purpose |
| Preservation in ethanol (preferably 90%) | Maintain sample integrity for lab analysis | Avoid formalin/isopropyl when possible; boiling before storage helps retain morphology |
| Labeling containers | Ensure evidence chain-of-custody | Include: Location, date/time, case number, description, collector's name |
| Use soft brushes to remove eggs and early larvae | Prevent damage to fragile specimens | Avoid tweezers for delicate samples |
| Search clothing folds for larvae | Ensure complete sampling of colonized regions | Check both at crime scene and morgue |
| Soil sampling (10 cm depth) | Detect pupating larvae beneath or near the body | Store in ventilated containers, label properly, freeze at sub-zero temperature |
| Accurate documentation of all findings | Court-admissible forensic evidence | Every sample must be traceable and tied to investigation details |

### 2.9. Collecting Insect Evidence During Body Transport and Autopsy

When handling a body removed from a crime scene, it is often placed in sealed plastic bags for preservation and transportation. The body may be in an advanced stage of decomposition, requiring careful procedures to collect insect evidence without losing or damaging it [49].

**First: External Examination of the Plastic Bag**

If the body is infested with large numbers of insects, the outer surface of the bag should be examined immediately upon receipt. Some insects or larvae often escape from within the bag and attach to the outside. The forensic entomologist should:

- Collect any adult insects or larvae found on the outer surface of the bag.
- Initially classify them by stage (larva, adult, egg, etc.).
- Document each specimen using a separate identification card that includes the date, case number, insect stage, and location where it was found.

**Second: Examining the inner surface of the bag when opened**

When opening the bag in the autopsy room, examining the inner surfaces of the bag is a crucial step, as the temperature change between the outside and inside may encourage insects to leave the body and crawl along the inner walls of the bag.

- Each part of the bag should be examined to determine if any insects have migrated inside it.
- The location of each insect relative to the body (head, thorax, abdomen, limbs) is documented.
- These samples are carefully collected using specialized tools (a soft brush or fine forceps), and each sample is placed in a container with a detailed label.

**Third: Refrigeration and Transport Conditions**

Carcasses are often stored in refrigerated units prior to autopsy, and preservation may last for hours or even days. Therefore, environmental factors that affect insect growth and developmental stages must be accurately recorded, including:

- Total refrigeration time.
- The temperature of the refrigerator in which the carcass was placed.
- The temperature of the autopsy room at the time of examination.
- The temperature of the ambulance or transport vehicle during transportation from the crime scene to the morgue.

This documentation is essential for accurately analyzing insect developmental stages, especially when used to estimate post-mortem interval (PMI). Temperature changes directly affect insect growth rates [50]

### 2.10. Small Arthropods and Their Role in Forensic Analysis

A variety of small arthropods may be found on fresh corpses or surrounding clothing Table 4, including fleas, ticks, mites, lice, and lice eggs. These organisms often attempt to leave the refrigerated body and attach themselves to clothing or the surrounding environment. It is also important to be aware of the possibility of some parasites being present directly on the corpse. Therefore, it is recommended to observe the hair around the scalp for lice eggs (nits), as this is an important indicator in forensic analysis [1].

**Table 4:** The importance of arthropods on corpses [14, 51]

| Type | Scientific Name | Common Location | Forensic Significance |
|---|---|---|---|
| Head Lice | *Pediculus humanus capitis* | Scalp, behind ears | Presence of lice or nits suggests long-term infestation; useful in estimating time of death |
| Nits (Lice Eggs) | – | Hair near the scalp | Confirms lice infestation; may indicate victim's hygiene and time before death |
| Eyelash Mites | *Demodex sp.* | Base of eyelashes, facial hair | Indicates pre-death skin activity; may reflect general health condition |
| Fleas | *Pulex irritans* | Clothing, skin folds | May abandon the corpse postmortem; presence suggests recent proximity to a living host |
| Ticks | *Ixodes spp.* | Scalp, armpits, between toes/fingers | Indicates environmental exposure; useful for determining place of death |
| Skin Mites (Scabies) | *Sarcoptes scabiei* | Skin folds, sensitive areas | Sign of scabies infection; reflects the person's medical history before death |
| Fly Larvae (Maggots) | *Calliphora*, *Lucilia*, *Sarcophaga* | Natural orifices, wounds, decomposing skin | Primary indicators for estimating (PMI) based on developmental stage |

### 2.11. Forensic Entomology Applications

Forensic entomology is a vital tool in criminal investigations, as it can extract sensitive and accurate evidence that contributes to solving crimes and determining the nature of death. The following are the most prominent practical applications of this science Table 5 [52].

**Table 5:** Forensic Applications of Different Insect Groups [53]

| Insect Type | Forensic Application | Explanation |
|---|---|---|
| Blowflies (*Calliphora, Lucilia*) | Estimating time of death (PMI) | Based on larval developmental stage and environmental conditions |
| Fly larvae | Toxicological analysis | Larvae retain toxins from the tissues they feed on |
| Beetles (*Dermestes, Necrobia*) | Determining stage of decomposition | Presence indicates long-term exposure and advanced tissue decay |
| Lice, Fleas, Ticks | Elder or child neglect detection | Infestation often found in poorly cared-for individuals |
| Insects on suspect's clothes | Crime scene linkage | Matching insects to a specific environment or location |
| Insects on drug shipments | Smuggling route identification | Specific insect species reveal geographic origin of contraband |

## 2.12. The Sequence of Insect Infestations on Corpses and Their Forensic Uses

Forensic studies indicate that insect infestations of corpses follow a precise chronological sequence after death. Certain species of flies begin laying their eggs on the body immediately after death, while other species do not begin infesting the body until signs of decomposition and decay appear. Beetles, on the other hand, appear later, when tissues are clearly eroded and the body has reached advanced decomposition. Some insects are also used to reveal the genetic fingerprint of a decomposing corpse. Human body cells remain within the larvae that feed on human tissue. From these larvae, DNA can be extracted and analyzed. The presence of toxins or drugs can also be detected using chemical tests on the bodies of larvae or insects that have fed on the body [54].

Insects tend to seek suitable locations to lay their eggs, and these are often natural body openings such as the eyes, mouth, nose, and ears, as well as the anus and genital areas. In the case of open wounds, insects prefer these areas due to their easy access to tissue. Therefore, the atypical distribution of larvae on the body is considered an indicator of pre-mortem wounds or injuries. Furthermore, the species of insects associated with drug shipments, such as hashish and marijuana, can be used to determine the source of these shipments. The insects associated with these shipments vary depending on the geographic region, allowing the origin of the contraband to be traced by studying the insect species associated with them Table 6 [34].

**Table 6:** Forensically Important Insects and Their Role in Decomposition

| Category | Scientific Name | Stage of Appearance | Preferred Oviposition /Feeding Site | Forensic Use |
|---|---|---|---|---|
| Blowflies | *Calliphora vicina* | Early (hours after death) | Natural openings (mouth, nose, eyes) | Estimating postmortem interval (PMI) |
| Blowflies | *Lucilia sericata* | Early (12–24 hours) | Wounds and natural orifices | Toxicological analysis (larval gut) |
| Flesh flies | *Sarcophaga spp.* | Early to mid stage | Moist tissues and wounds | Tracing body movement or tampering |
| Dermestid beetles | *Dermestes maculatus* | Late (days to weeks) | Dry tissue, skin, and bones | Confirming advanced decomposition |
| Beetles | *Necrobia rufipes* | Very late stage | Dried tissues and bones | Indicating long postmortem interval |
| Ticks/Mites | *Ixodes spp., Demodex spp.* | Any stage | Hair, scalp, skin | Neglect, abuse detection |

## 2.13. Practical Examples of Forensic Entomology Applications

**Table 7:** Summary of Case Study No. 1 – Forensic Entomology Application

| Parameter | Details |
|---|---|
| Date of Discovery | Mid-November |
| Location | Southeastern United States, residential basement (shallow grave) |
| Victim Details | Young female, severely decomposed |
| Cause of Death | Single gunshot wound to the head (likely small-caliber rifle) |
| Entomological Evidence | Larvae and pupae from two fly species |
| Key Developmental Stage Found | Fourth instar larvae (longer-developing fly species) |
| Environmental Data Reviewed | Local weather records, soil temperature |
| Estimated PMI (Post-Mortem Interval) | Approximately 28 days before discovery |
| Forensic Conclusion | Insect development consistent with a 28-day timeline |
| Investigative Outcome | Suspect identified and confessed to the crime; timeline confirmed by entomological analysis |
| Forensic Significance | Accurate PMI estimation despite advanced decomposition and body concealment in buried soil |

**Table 8:** Summary of Case Study No. 2 – Estimating Time Since Death from Maggot Development

| Parameter | Details |
|---|---|
| **Location of Discovery** | Wooded area, Northern Europe |
| **Discovery Context** | Partially skeletonized male body found beneath a tree |
| **State of Decomposition** | Advanced; traditional forensic pathology deemed inadequate |
| **Insect Evidence** | Numerous larvae of *Lucilia sericata* (blowfly) collected from remaining soft tissues |
| **Developmental Stage Identified** | Third instar larvae |
| **Rearing Conditions** | Larvae reared in laboratory under controlled conditions |
| **Environmental Data Reviewed** | Local temperature records and regional climate data |
| **Larval Development Period** | Estimated 10 days to reach third instar stage |
| **Estimated Colonization Time** | Approximately 10–12 days prior to discovery |
| **Postmortem Interval (PMI)** | Estimated 10–13 days |
| **Investigative Outcome** | Matched with a missing person reported 2 weeks earlier; identity confirmed via dental records |
| **Forensic Significance** | Entomological evidence enabled PMI estimation and positive identification when traditional methods failed |

**Table 9:** Summary of Case Study No. 3 – PMI Estimation Using Black Flies

| Parameter | Details |
|---|---|
| **Season and Location** | Summer; rural street in a northern U.S. state |
| **Victim Details** | Unidentified young female |
| **Cause of Death** | Gunshot wound to the right side of the head |
| **Insect Evidence** | Adult black flies and larvae collected from the head wound |
| **Insect Type Identified** | Black flies (typically attracted to fresh corpses) |
| **Environmental Assessment** | Local weather conditions and crime scene photographs analyzed |
| **Estimated Colonization Period** | Insect activity indicated colonization began shortly after death |
| **Estimated Postmortem Interval** | Approximately 5 days before discovery |
| **Investigative Actions** | Police checked missing persons reports from 5 days prior |
| **Identification Outcome** | Victim identified; boyfriend suspected |
| **Case Resolution** | Suspect found dead in hotel; suicide note confirmed he killed the victim 5 days before body discovery |
| **Forensic Significance** | Entomological analysis accurately determined PMI and supported confession timeline |

**Table 10:** Summary of Case Study No. 4 – Elder Abuse Detected via Forensic Entomology

| Parameter | Details |
|---|---|
| **Location** | Private elderly care facility |
| **Incident Type** | Suspected elder neglect and abuse |
| **Victim Details** | Elderly resident, found malnourished and dehydrated with untreated bedsores |
| **Insect Evidence** | Fly larvae infesting open wounds |
| **Insect Species Identified** | *Lucilia illustris* |
| **Colonization Characteristics** | Species known to colonize necrotic tissue in living patients (indicative of myiasis) |
| **Larval Development Stage** | Larval size and stage suggested colonization began 3–4 days earlier |
| **Post-Investigation Findings** | Infestation occurred while patient was alive, indicating ongoing medical negligence |
| **Forensic Significance** | Timeline of infestation helped establish neglect over several days |
| **Legal and Medical Outcomes** | Legal action taken against the facility; patient received emergency care and was relocated |

**Table 11:** Summary of Case Study No. 5 – Insect Evidence on a Vehicle in Drug Trafficking Case

| Parameter | Details |
|---|---|
| **Case Type** | Suspected cross-border drug trafficking |
| **Evidence Location** | Front grille and windshield of impounded vehicle |
| **Insect Evidence Collected** | Numerous dead insects |
| **Species Identified** | *Megaselia scalaris, Haematobia irritans* |
| **Insect Origin** | Tropical species not native to the impound region |
| **Entomological Conclusion** | Species indicate recent travel through tropical zones, likely northern South America |
| **Forensic Significance** | Helped determine travel route and support claims of international border crossing |
| **Investigative Outcome** | Insect evidence used to corroborate trafficking timeline and strengthen case against the suspect |

**Table 12:** Summary of Case Study 6: Use of Pollen as Forensic Evidence – Noosa Heads, Australia

| Element | Details |
|---|---|
| **Year** | 1996 |
| **Location** | Noosa Heads, Queensland, Australia |
| **Victim** | Young mother of two children |
| **Discovery** | Body found dumped in a park among flowering ”nose grass” (native Australian plant) |
| **Suspect** | A man from nearby town of Gympie |
| **Suspicion** | Victim’s car found near suspect’s home with scattered flower petals and plant remnants inside |
| **Denial by Suspect** | Claimed not to have visited Noosa or driven the victim’s car |
| **Forensic Expert** | Dr. Lynne Milne – Forensic botanist, University of Western Australia |
| **Method Used** | Pollen analysis (pollen fingerprinting) from car interior, flower petals, and suspect’s clothing |
| **Key Finding** | Pollen matched precisely with the flowering grass from Noosa, not Gympie |
| **Legal Impact** | Strong botanical evidence linked suspect to the crime scene; convicted and sentenced to life |

**Table 13:** Summary of Case Study 7: Wife Murders Husband – Insect Evidence Uncovers the Truth

| Element | Details |
|---|---|
| **Location** | United States of America |
| **Crime** | Woman claimed her husband had been at home with her the previous day |
| **Contradiction** | Forensic entomologist discovered insect larvae (maggots) had been on the body for four days |
| **Insect Evidence** | Presence and developmental stage of maggots indicated death occurred four days earlier |
| **Investigation Outcome** | The timeline disproved the wife’s statement |
| **Confession** | Under pressure from the evidence, the wife confessed to killing her husband |
| **Impact** | Demonstrated the value of forensic entomology in determining time of death and solving the case |

**Table 14:** Summary of Case Study 8: Brother Murders Sister – Absence of Insects Exposes the Lie

| Element | Details |
|---|---|
| **Location** | Not specified (possibly United States) |
| **Crime** | Man claimed he found his sister had committed suicide by hanging herself near an open window |
| **Key Observation** | Forensic experts found no signs of fly activity on the body |
| **Insect Evidence** | Absence of flies indicated that windows had been closed for at least 21 hours |
| **Contradiction** | The suspect’s claim of an ”open window” was false |
| **Confession** | Confronted with forensic insect evidence, he confessed to murdering his sister |
| **Impact** | Showed that both presence and absence of insect activity can be crucial in crime reconstruction |

**Table 16:** Summary of Case Study 10: Severely Burned Body – Finland (1965)

| Element | Details |
|---|---|
| **Location** | Island in Finland |
| **Date Discovered** | 25 August 1965 |
| **Condition** | 25 kg of charred human remains found inside a circular concrete container |
| **Last Seen Alive** | 16 August 1965 |
| **Insect Evidence** | Presence of fly eggs and larvae on the remains |
| **Egg deposition pattern** | Death occurred before 24 August, based on local fly behavior and egg-laying timelines |
| **Larval development** | Narrowed estimated time of death to before 18 August |
| **Sunlight analysis** | No sun-loving fly species were found → body was kept in shade |
| **Conclusion** | Insects provided crucial evidence for time and environmental conditions of death |

**Table 15:** Summary of Case Study 9: Cocaine Trafficking – Insect Traces Reveal Country of Origin

| Element | Details |
|---|---|
| **Location** | Florida, United States |
| **Crime** | Police discovered large quantities of cocaine without knowing its origin |
| **Key Observation** | A dead insect was found inside one of the drug packages |
| **Insect Evidence** | A forensic entomologist identified the insect as native to the forests of Honduras |
| **Conclusion** | The insect provided a geographic fingerprint, indicating the cocaine was likely sourced or packaged in Honduras |
| **Impact** | Helped authorities trace the origin of the narcotics and informed international trafficking investigations |

**Table 17:** Summary of Case Study 11: Newlywed Couple Exonerated – France

| Element | Details |
|---|---|
| **Location** | France, inside a residential chimney |
| **Discovery** | Body found by workers during home renovation |
| **Initial Suspects** | A newly married couple who had recently rented the apartment |
| **Insect Evidence** | Analysis of insect life stages on the body |
| **Forensic Entomology Findings** | |
| **Time of death estimation** | Insects showed the person died approximately six months earlier |
| **Apartment rental date** | Couple moved in just one week prior to the body's discovery |
| **Outcome** | The couple was proven innocent; former homeowner confessed to the murder |

**Table 18:** Summary of Case Study 12: Mosquito Reveals Car Thief – Finland

| Element | Details |
|---|---|
| **Location** | Lapua, Finland (theft); Seinäjoki (car recovered) |
| **Crime** | Car theft in June, vehicle found 20 km from original location |
| **Evidence Found** | A female mosquito inside the stolen car |
| **Forensic Technique** | DNA analysis of the blood meal from the mosquito's abdomen |
| **Outcome** | Identified a suspect from police records using the mosquito's blood sample |
| **Result** | Strong link to the crime scene confirmed via entomological DNA evidence |
| **Significance** | Demonstrates how even a small insect can provide critical evidence in non-lethal criminal cases |

## 3. Methodology

The study relied on an analysis of scientific literature and previous studies, in addition to a review of forensic reports on documented cases in which forensic entomology was used. The steps for collecting, preserving, and analyzing samples from crime scenes in the laboratory using microscopes and DNA techniques were also presented.

## 4. Results

The application of forensic entomology has demonstrated remarkable advancements in the field of forensic evidence detection. Among the most important results are the following Table 7.

**Table 19:** Forensic Entomology Findings and Their Practical Applications

| Key Finding | Description | Practical Application |
|---|---|---|
| Estimation of Post-Mortem Interval | Accurate determination of time since death based on insect life cycles | Time of death estimation in criminal investigations |
| Detection of Body Relocation | Analysis of insect species to identify discrepancies in environmental origin | Verifying or disproving crime scene manipulation |
| Detection of Toxins and Drugs | Examination of insect larvae to identify toxic substances post-tissue decay | Support for toxicological reports |
| Differentiation Between Natural and Criminal Deaths | Unusual insect succession patterns may indicate foul play or unnatural death | Clarifying cause and manner of death |
| Support of Biological Evidence in Court | Insect evidence used as scientific testimony in legal proceedings | Enhancing the reliability of forensic evidence |
| Environmental Tracking of Corpse Location | Linking insect species to specific geographical or environmental zones | Identifying potential original crime scene |
| Aid in Advanced Decomposition or Absence of Human Samples | Use of insect analysis when human tissues are too decomposed | Solving cases in extreme or delayed conditions |

**The study concluded the results can be obtained from forensic entomology applications include:**

- Sometimes, it can help determine the cause of death. Some insect species are particularly attracted to open wounds or bleeding sites, which can indicate pre-mortem injuries or the manner of death, such as suffocation or stabbing.
- It can help assess the conditions at the scene of death (environmental/geographical). Insects react differently to temperature, humidity, and lighting, so their diversity and quantity can be used to assess whether death occurred indoors or outdoors, wet or dry.
- It can help verify evidence tampering or concealment of the body. The irregular succession or absence of expected insect species may indicate human intervention to modify the crime scene or delay decomposition.
- It can also accurately determine the time interval between death and finding of the body. Thanks to advances in genetic analysis and accurate insect age estimation, the time interval can be determined within days or even hours, sometimes supporting or contradicting witness accounts.

## 5. Conclusion

The prevalence of insects in various environments and their feeding on decomposing bodies and dead materials found on the ground supports the hypothesis that these insects can be used in crime detection, as they play a crucial role in crime-fighting techniques. Through ongoing research and experimentation, forensic entomology could become a primary tool in criminal investigations and crime scene management. Forensic entomology studies insects that feed on corpses. This science has played key roles in uncovering forensic evidence and is a very useful method for estimating the time elapsed after death. Forensic scientists enjoy a prestigious position in developed countries. However, forensic entomology is still relatively new. Well-trained entomologists are crucial for interpreting crime scenes. Generally, our understanding of the biology and ecology of animals associated with decomposing bodies needs to be improved. Only then will the emerging field of forensic entomology successfully contribute to solving many criminal cases. However, it is important to acknowledge some of the challenges faced in accurately interpreting entomological data, such as environmental influences (temperature, humidity, soil type) and the variable behavior of insects depending on geographic location and season. Therefore, accurate and up-to-date local databases of insect species and their succession patterns are needed to strengthen the reliability of analyses across different geographical contexts

**Recommendations**

- Training police officers as well as investigation officers in special courses to collect insect or arthropod samples from the deceased at the crime scene in a correct manner.
- Training forensic experts, medical officials as well as forensic science officers to collect insect or arthropod samples from the deceased during post-mortem examination in a correct manner.
- The necessity of unifying the efforts of all research centers and science colleges in Iraq in order to create a detailed database of all insects present in our country, which differ according to the climate of each geographical area.
- Establishing a database of insects that help determine the time of death in murder crimes.
- Conducting documentary research for all studies and research in this field to be the nucleus of the database.
- Developing a framework to enhance the justice system based on cooperation between higher education institutions.

## Article Information

**Conflict of Interest:** The author declares no conflict of interest.

**Acknowledgements:** The authors express their deep appreciation and gratitude to the researchers, authors, institutions and organizations mentioned in the sources.

**Disclaimer (Artificial Intelligence):** The author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.), and text-to-image generators have been used during writing or editing of manuscripts.

**Competing Interests:** Authors have declared that no competing interests exist.

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